# The EURISOL Beta-beam facility

The beta-beam concept for the generation of an electron (anti-)neutrino beam was proposed by Piero Zucchelli (CERN) in 2002. A first study of the possibility of using the existing CERN machines for the acceleration for radioactive ions to a relativistic gamma of roughly 100, for later storage in a new decay ring of approximately the size of SPS, was made in 2002. The results from this very first short study were very encouraging.
In 2004 it was decided to incorporate a design study for the beta-beam within the EURISOL DS proposal. EURISOL is a project name for a next-generation radioactive beam facility based on the ISOL method for the production of intense radioactive beams for nuclear physics, astrophysics and other applications. The proposal was accepted with the beta-beam task as an integral part. The design study officially started 1 February 2005 and will run for 4 years resulting in a conceptual design report for a beta-beam facility.

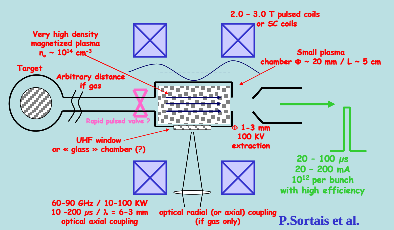
## General concept

For the EURISOL beta-beam facility we propose to use a thick ISOL target for production of $^{6}He$ and $^{18}Ne$ as both isotopes can be produced in large quantities and are easy to handle. Neither of the isotopes have any long-lived daughter products that could create a problem in the low-energy part of the facility. A high frequency (60 GHz) ECR source has been identified as a possible highly efficient tool to create sufficiently short bunches after the target for multi-turn injection into a synchrotron. For the first stage of acceleration, it is proposed to use the 100 Mev/u linac of the EURISOL facility. Further acceleration can be done with a new rapid cycling synchrotron (RCS), the PS and finally the SPS. A new injection and stacking method has been proposed to keep the duty factor of the decay ring low. The method makes use of a dispersion orbit in the decay ring to avoid that the injection elements interfere with the circulating beam, bunch rotation to bring the fresh bunches to the central orbit and asymmetric bunch merging to take the newly injected ions into the centre of the circulating bunch.

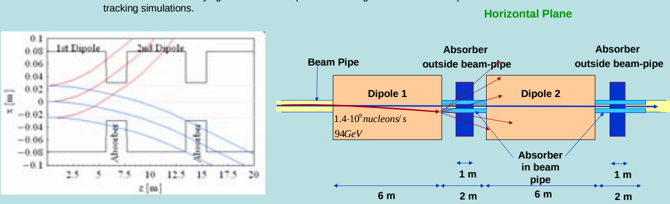
An overview of the EURISOL beta-beam facility. In the tope part of the picture the EURISOL like production, bunching and pre-acceleration complex can be seen. This complex feeds a new Rapid Cycling Synchrotron which feeds PS and SPS chain of synchrotrons. The ions are finally transferred to the decay ring and merged with the stored ion bunches.

The $^{6}He$ ions can be produced through a two step process. In the first stage protons hit a cooled robust primary target which can take a high beam power. The neutrons produced in the primary target will to large extent interact in the secondary target of Beryllium and produced $^{6}He$ and $^{4}He$.


For the EURISOL beta-beam facility a 60 GHz ECR source operating in pre-glow mode is studied. Tests with a less optimized system at 30 GHz are encouraging but there is still a lot of work to be done to reach the high efficiencies required for the beta-beam facility.




The superconducting dipoles in the decay ring must be protected with absorbers from the daughter nuclei of the ions decaying in the arcs. The process is being studied with the help of FLUKA and tracking simulations.

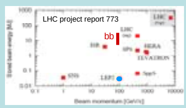


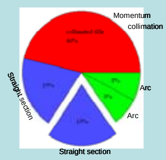

## The technical challenges of the EURISOL beta-beam complex

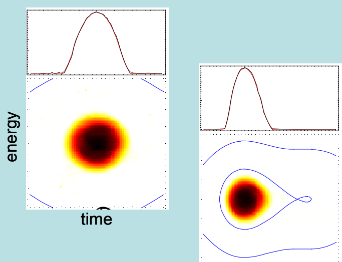
The main technical challenges of the beta-beam facility are:
- The production rate with the ISOL technology
- The bunching of the beam in a high frequency ECR source
- The high efficiency required for the bunching scheme and the wish to possible have all produced ions in a single charge state
- The additional losses compared to stable ion acceleration due to radioactive decay
- The collimation of the high power beam in the decay ring
- The magnet protection system required to avoid damage from the decay products to the SC magnets in the arcs of the decay ring
- The requested low duty factor of the decay ring

Within the EURISOL design study these technical challenges are being addressed:
- Within EURISOL task 3 (direct targets) and task 4 (multi MW target station) different target concepts for the beta-beam are being studied
- Within task 9 (beam preparation) a 60 GHz ECR source operating withy pre-glow for bunching is being studied
- Within task 12 (beta-beam task) the acceleration, the decay losses influence on the vacuum, the collimation, the magnet protection and the accumulation of ions in short bunches in the decay ring are being studied

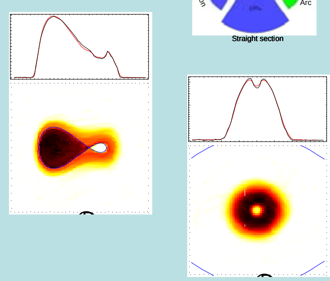
In the decay ring 19% of the ions will decay in the straight section pointing towards the experiment. A large fraction of the beam is lost longitudinally during beam stacking and has to be collimated away in one of the straight sections to not cause problems elsewhere. In the top figure the stored beam energy versa the beam momentum for the beta-beam is compared to other facilities.




The asymmetric bunch merging has been tested in the PS merging a high intensity proton bunch with a small portion of empty phase space from an adjacent bunch. The process works very well and with high efficiency.



## Conclusions

The main challenge for the study is to achieve the annual rate required for a physics reach that would make the beta-beam an attractive option for neutrino physics in 10-15 years time. Detailed physics studies show that a beta-beam facility must deliver at least 1018 (anti-)neutrinos at the end of the straight section per year for a MegaTon detector to be of any interest within this time frame.
The physics reach of the EURISOL DS scenario is competitive for $\theta_{13} > 1^{O}$. Its usefulness depends on the short/mid-term findings by other neutrino search facilities.
There are plenty of new ideas for the beta-beam, such as having a larger decay ring with a higher (Lorenz) gamma or using electron capture decaying isotopes to produce a monochromatic neutrino beam. Recently, Carlo Rubbia et al. have proposed a method to produce very large numbers of ions in a small ring with an internal gas target and to use high-Q value isotopes such as $^{8}Li$ and $^{8}B$ to send a neutrino beam from CERN to the Gran Sasso laboratory. This idea is very promising and would make the beta-beam competitive with even a neutrino factory. We hope to pursue these ideas in a future study beyond EURISOL DS.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EURISOL Design Study

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